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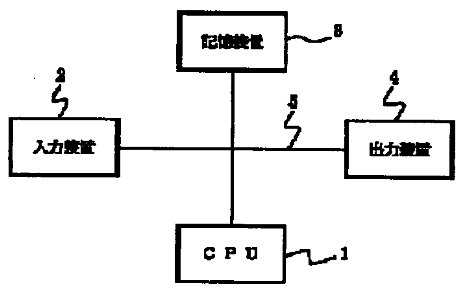
(54) METHOD AND DEVICE FOR SUPPORTING DESIGN OF LENS OR THE LIKE

(57) Abstract

PURPOSE: To efficiently calculate an optimal design value by properly setting variable difference amount in the design of lens, etc., by the method of descent.

CONSTITUTION: A CPU 1 calculates the eigen value distribution information of the product matrix $(A_v{}^TA_v)$ between the Jacobian matrix A_v having the variable amount of the characteristic (evaluation function $F_v(X_v)$) for variable difference amount δx_j of the system being the design object as an element and transpose of matrix $A_v{}^T$ and sets the variable difference amount δx_j by using the eigen value distribution information. Instead of the eigen value of the product matrix $(A_v{}^TA_v)$, the square value of the singular value of the Jacobian matrix A may be used.



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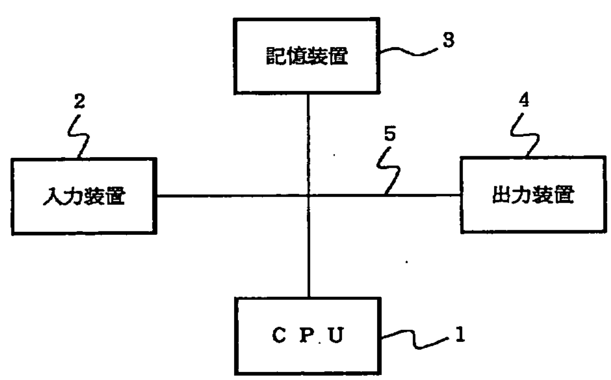
(54)【発明の名称】　レンズ等の設計支援装置及び方法

(57)【要約】
【目的】　降下法によるレンズ等の設計において、変数差分量を適切に設定し、最適な設計値を効率良く算出する。
【構成】　ＣＰＵ１は、設計対象となる系の変数差分量 δx_j に対する系の特性（評価関数 F_V（X_V））の変化量を要素に持つヤコビ行列 A_V とその転置行列 A_V^T との積行列（$A_V^T A_V$）の固有値分布情報を演算し、その固有値分布情報を用いて変数差分量 δx_j の設定を行う。前記積行列（$A_V^T A_V$）の固有値に代えて、ヤコビ行列Ａの特異値の自乗値を用いてもよい。



性補正項の初期値の中央値に略一致するように前記変数の差分量を設定することを特徴とする請求項１５記載の設計支援装置。

【請求項１８】　前記積行列の固有値分布の平均値が最適化を図る目的関数に対する前記変数に対応した非線形性補正項の初期値の中央値に略一致するように前記変数の差分量を設定することを特徴とする請求項１５記載の設計支援装置。

【請求項１９】　前記積行列の固有値分布の中央値が最適化を図る目的関数に対する前記変数に対応した非線形性補正項の初期値の平均値に略一致するように前記変数の差分量を設定することを特徴とする請求項１５記載の設計支援方法。

【請求項２０】　前記積行列の固有値分布の平均値が最適化を図る目的関数に対する前記変数に対応した非線形性補正項の初期値の平均値に略一致するように前記変数の差分量を設定することを特徴とする請求項１５記載の設計支援方法。

【請求項２１】　前記積行列の固有値分布情報と該固有値分布に対応して設定された所定の重み付け情報とを用いて前記変数の差分量を設定することを特徴とする請求項１５記載の設計支援方法。

【請求項２２】　複数の構成要素からなる設計対象の系が所望の特性となるように、前記複数の構成要素を局所的に変更して最適化する降下法によりレンズ等の設計を支援する設計支援方法において、
前記複数の構成要素に対応する変数の差分量に対する前記系の特性の変化量を要素に持つヤコビ行列（A_V）の特異値の自乗値分布情報を演算し、
該自乗値分布情報を用いて前記変数の差分量を設定することを特徴とするレンズ等の設計支援方法。

【請求項２３】　最適化を図る目的関数に対する前記変数に対応した非線形性補正項の初期値が、前記ヤコビ行列の特異値の自乗値分布の最小値と最大値の間に存在するように前記変数の差分量を設定することを特徴とする請求項２２記載の設計支援方法。

【請求項２４】　前記ヤコビ行列の特異値の自乗値分布の中央値が最適化を図る目的関数に対する前記変数に対応した非線形性補正項の初期値の中央値に略一致するように前記変数の差分量を設定することを特徴とする請求項２２記載の設計支援方法。

【請求項２５】　前記ヤコビ行列の特異値の自乗値分布の平均値が最適化を図る目的関数に対する前記変数に対応した非線形性補正項の初期値の中央値に略一致するように前記変数の差分量を設定することを特徴とする請求項２２記載の設計支援方法。

【請求項２６】　前記ヤコビ行列の特異値の自乗値分布の中央値が最適化を図る目的関数に対する前記変数に対応した非線形性補正項の初期値の平均値に略一致するように前記変数の差分量を設定することを特徴とする請求項２２記載の設計支援方法。

【請求項２７】　前記ヤコビ行列の特異値の自乗値分布の平均値が最適化を図る目的関数に対する前記変数に対応した非線形性補正項の初期値の平均値に略一致するように前記変数の差分量を設定することを特徴とする請求項２２記載の設計支援方法。

【請求項２８】　前記ヤコビ行列の特異値の自乗値分布情報と該自乗値分布に対応して設定された所定の重み付け情報とを用いて前記変数の差分量を設定することを特徴とする請求項２２記載の設計支援方法。

【発明の詳細な説明】

【０００１】

【産業上の利用分野】本発明は、複数の構成要素からなる対象の系が所望の特性となるように、該複数の構成要素を局所的に変更していく最適化手法の内の降下法を用いた設計支援装置及び方法に関し、例えばレンズ設計、ＬＳＩの最適パターン設計、建築物の設計などの支援を行うものに関する。

【０００２】

【従来の技術】設計の対象となる系を構成する構成要素をｎ個の要素から成る変数ベクトル

【０００３】

【数１】

$$X_v=[X_1, \cdots, X_n]^T \qquad (1)$$

で表わし、該対象の特性を評価する量をｍ個の要素から成る評価関数ベクトル

【０００４】

【数２】

$$F_v(X_v)=[F_1(X_v), \cdots, F_m(X_v)]^T \qquad (2)$$

で表わす。ただし、

【０００５】

【数３】

$$F_k(X_v)=w_k\{f_k(X_v)-f_{k,tar}\} \qquad (3)$$

である。ここで、添字vはX_V，F_Vがベクトル（又は行列）であることを示すために付加したものである。また$f_k(X_V)$，$f_{k,tar}$はそれぞれ各特性値を表わす評価関数の値とその目標値であり、w_kは重み付け係数である。これらの評価関数には所望の値にすることを目的とした特性値の他、制約条件値を含めてもよい。降下法では、一般に各評価関数値の目標値からのずれ（誤差）量が最小になるように解が求められ、そのために単一評価尺度として、次式で表わされる目的関数を用いる。

【０００６】

【数４】

$$\phi(X_v)=F_v^T(X_v)F_v(X_v) \qquad (4)$$

（４）式で与えられる目的関数を特にレンズ設計の分野では、メリット関数と呼び。（４）式にニュートン－ラフソン（Newton-Raphson）法を適用すると、局所的最小

持つヤコビ行列（A_V）と該ヤコビ行列の転置行列（A_V^T）との積で構成される積行列（$A_V^TA_V$）の固有値分布情報を演算する固有値分布情報演算手段と、該固有値分布情報を用いて前記変数の差分量を設定する差分量設定手段とを設けるようにしたものである。

【００１７】同じ目的を達成するため本発明は、複数の構成要素からなる設計対象の系が所望の特性となるように、前記複数の構成要素を局所的に変更して最適化する降下法によりレンズ等の設計を支援する設計支援方法において、前記複数の構成要素に対応する変数の差分量に対する前記系の特性の変化量を要素に持つヤコビ行列（A_V）と該ヤコビ行列の転置行列（A_V^T）との積で構成される積行列（$A_V^TA_V$）の固有値分布情報を演算し、該固有値分布情報を用いて前記変数の差分量を設定するようにしたものである。

【００１８】また、前記設計支援装置又は方法において、最適化を図る目的関数に対する前記変数に対応した非線形性補正項の初期値が前記積行列の固有値分布の最小値と最大値の間に存在するように前記変数の差分量を設定したり、前記積行列の固有値分布の中央値が最適化を図る目的関数に対する前記変数に対応した非線形性補正項の初期値の中央値に略一致するように前記変数の差分量を設定したり、前記積行列の固有値分布の平均値が最適化を図る目的関数に対する前記変数に対応した非線形性補正項の初期値の中央値に略一致するように前記変数の差分量を設定したり、前記積行列の固有値分布の中央値が最適化を図る目的関数に対する前記変数に対応した非線形性補正項の初期値の平均値に略一致するように前記変数の差分量を設定したり、前記積行列の固有値分布の平均値が最適化を図る目的関数に対する前記変数に対応した非線形性補正項の初期値の平均値に略一致するように前記変数の差分量を設定したり、前記積行列の固有値分布情報と該固有値分布に対応して設定された所定の重み付け情報とを用いて前記変数の差分量を設定したりすることが望ましい。

【００１９】さらに、前記設計支援装置又は方法において、「積行列（$A_V^TA_V$）の固有値分布」に代えて、「ヤコビ行列（A_V）の特異値の自乗値分布」を用いてもよい。

【００２０】

【作用】請求項１の装置又は請求項１５の方法によれば、複数の構成要素に対応する変数の差分量に対する系の特性の変化量を要素に持つヤコビ行列（A_V）と該ヤコビ行列の転置行列（A_V^T）との積行列（$A_V^TA_V$）の固有値分布情報が演算され、該固有値分布情報を用いて前記変数の差分量が設定される。

【００２１】請求項８の装置又は請求項２２の方法によれば、複数の構成要素に対応する変数の差分量に対する前記系の特性の変化量を要素に持つヤコビ行列（A_V）の特異値の自乗値分布情報が演算され、該自乗値分布情報を用いて前記変数の差分量が設定される。

【００２２】

【実施例】以下本発明の実施例を図面を参照して説明する。

【００２３】図１は本発明の一実施例に係る設計支援装置の構成を示す図である。この装置は、設計対象となる系の構成要素に対応する変数の最適化を行うために、種々の演算を実行するＣＰＵ（中央処理装置）１と、使用者がＣＰＵ１にデータや演算命令を入力するための入力装置２と、ＣＰＵ１が実行するプログラムや演算途中のデータ等を格納する記憶装置３と、演算結果をディスプレイに表示したり、プリンタにより印刷する出力装置４とから構成される。これらの構成要素１～４は、バス５により相互に接続されている。

【００２４】次に、ＣＰＵ１で実行される処理の概要を説明する。

【００２５】先ず、前述したヤコビ行列A_Vとその転置行列A_V^Tとの積行列（$A_V^TA_V$）を以下のように固有値分解する。

【００２６】

【数１２】

$$(A_v{}^T A_v) = V_v S_v V_v{}^T \qquad (13)$$

ここで、V_Vはｎ×ｎの直交行列であり、S_Vは（１４）式に示すように、積行列（$A_V^TA_V$）のｎ個の固有値を要素に持つｎ×ｎの対角行列である。

【００２７】

【数１３】

$$S_V = \begin{bmatrix} S_1 & & 0 \\ & \ddots & \\ 0 & & S_n \end{bmatrix} \qquad (14)$$

こうして得られるｎ個の固有値s_1，・・・，s_nの分布は、一般に前述した変数の差分量δx_jを変化させるに伴って変化する。その際、差分量δx_jによって直接

【００２８】先ず、前述した評価関数ベクトルF_V（X_V）のX_{V0}近傍での線形近似式

【００２９】

【数１９】

$$
\begin{aligned}
&\delta\ (1/r_1)=1\times10^{-6},\ \delta\ (1/r_2)=1\times10^{-6}\\
&\qquad s_1=8.6\times10^{-13},\ s_2=2.2\times10^{-8}\ (\text{図}3\ (a))\\
&\delta\ (1/r_1)=1\times10^{-6},\ \delta\ (1/r_2)=1\times10^{-4}\\
&\qquad s_1=8.0\times10^{-10},\ s_2=2.3\times10^{-7}\ (\text{図}3\ (b))\\
&\delta\ (1/r_1)=1\times10^{-6},\ \delta\ (1/r_2)=1\times10^{-2}\\
&\qquad s_1=9.0\times10^{-10},\ s_2=2.1\times10^{-8}\ (\text{図}3\ (c))\\
&\delta\ (1/r_1)=1\times10^{-6},\ \delta\ (1/r_2)=1\times10^{0}\\
&\qquad s_1=5.5\times10^{-9},\ s_2=6.8\times10^{0}\ (\text{図}3\ (d))\\
&\delta\ (1/r_1)=1\times10^{-4},\ \delta\ (1/r_2)=1\times10^{-6}\\
&\qquad s_1=8.6\times10^{-18},\ s_2=2.2\times10^{-4}\ (\text{図}4\ (a))\\
&\delta\ (1/r_1)=1\times10^{-4},\ \delta\ (1/r_2)=1\times10^{-4}\\
&\qquad s_1=8.6\times10^{-9},\ s_2=2.2\times10^{-4}\ (\text{図}4\ (b))\\
&\delta\ (1/r_1)=1\times10^{-4},\ \delta\ (1/r_2)=1\times10^{-2}\\
&\qquad s_1=8.2\times10^{-5},\ s_2=2.3\times10^{-3}\ (\text{図}4\ (c))\\
&\delta\ (1/r_1)=1\times10^{-4},\ \delta\ (1/r_2)=1\times10^{0}\\
&\qquad s_1=5.5\times10^{-8},\ s_2=6.8\times10^{0}\ (\text{図}4\ (d))\\
&\delta\ (1/r_1)=1\times10^{-2},\ \delta\ (1/r_2)=1\times10^{-6}\\
&\qquad s_1=8.6\times10^{-13},\ s_2=2.2\times10^{0}\ (\text{図}5\ (a))\\
&\delta\ (1/r_1)=1\times10^{-2},\ \delta\ (1/r_2)=1\times10^{-4}\\
&\qquad s_1=8.6\times10^{-9},\ s_2=2.2\times10^{0}\ (\text{図}5\ (b))\\
&\delta\ (1/r_1)=1\times10^{-2},\ \delta\ (1/r_2)=1\times10^{-2}\\
&\qquad s_1=2.2\times10^{0},\ s_2=8.7\times10^{-5}\ (\text{図}5\ (c))\\
&\delta\ (1/r_1)=1\times10^{-2},\ \delta\ (1/r_2)=1\times10^{0}\\
&\qquad s_1=4.3\times10^{-1},\ s_2=8.5\times10^{0}\ (\text{図}5\ (d))\\
&\delta\ (1/r_1)=1\times10^{0},\ \delta\ (1/r_2)=1\times10^{-6}\\
&\qquad s_1=5.8\times10^{-18},\ s_2=5.2\times10^{+3}\ (\text{図}6\ (a))\\
&\delta\ (1/r_1)=1\times10^{0},\ \delta\ (1/r_2)=1\times10^{-4}\\
&\qquad s_1=5.8\times10^{-9},\ s_2=5.2\times10^{+3}\ (\text{図}6\ (b))\\
&\delta\ (1/r_1)=1\times10^{0},\ \delta\ (1/r_2)=1\times10^{-2}\\
&\qquad s_1=5.9\times10^{-5},\ s_2=5.2\times10^{+3}\ (\text{図}6\ (c)\\
&\delta\ (1/r_1)=1\times10^{0},\ \delta\ (1/r_2)=1\times10^{0}\\
&\qquad s_1=1.5\times10^{0},\ s_2=5.2\times10^{+3}\ (\text{図}6\ (d))
\end{aligned}
\qquad (22)
$$

以上について、それぞれの積行列（$A_V{}^TA_V$）の固有値分布は図３（ａ）から図６（ｄ）に示すようになる。これらの図は、ＣＰＵ１によって演算された固有値分布を出力装置４によって印刷したものである。各図で横軸に数値を指数表示し、その上の前記各固有値（s_1、s_2）の位置を＊で表わしている。また、横軸上に非線形性補正項ｄの初期値d_0の位置をＸで示し、それを中心とした非線形性補正項ｄの探索範囲（以下「ｄ探索範囲」という）を［＃＃・・・＃＃］で示してある。なお、本実施例では

d_0＝１．０　　　（２３）

とした。また、ｄ探索範囲を、

【００３９】

【数２０】

$$d_0\times10^{-6}\sim d_0\times0.5\times10^{6}\qquad (24)$$

とした。本発明は積行列（$A_V{}^TA_V$）の固有値分布情報から変数の差分量の適切な値を設定するものであり、前記ｄ探索範囲に固有値s_1，s_2ができるだけ多く含まれるものを設定した方がよいことが、レンズ設計の分野では経験的に分かっている。この場合には図３～６からも明らかなようにｄ探索範囲に固有値s_1，s_2が１つも含まれていないものが以下に示す場合（（２５）式）である。

【数２１】

$$
\begin{aligned}
&\delta\ (1/r_1)=1\times10^{-6},\ \delta\ (1/r_2)=1\times10^{-6}\quad (\text{図}3\ (a))\\
&\delta\ (1/r_1)=1\times10^{-6},\ \delta\ (1/r_2)=1\times10^{-4}\quad (\text{図}3\ (b))
\end{aligned}
\qquad (25)
$$

また固有値が１つ（s_1又はs_2）含まれているのが以下に示す場合（（２６）式）である。

【００４１】

【数２２】

$$
\begin{aligned}
&\delta\ (1/r_1)=1\times10^{-6},\ \delta\ (1/r_2)=1\times10^{-2}\quad (\text{図}3\ (c))\\
&\delta\ (1/r_1)=1\times10^{-6},\ \delta\ (1/r_2)=1\times10^{0}\quad (\text{図}3\ (d))\\
&\delta\ (1/r_1)=1\times10^{-4},\ \delta\ (1/r_2)=1\times10^{-6}\quad (\text{図}4\ (a))\\
&\delta\ (1/r_1)=1\times10^{-4},\ \delta\ (1/r_2)=1\times10^{-4}\quad (\text{図}4\ (b))\\
&\delta\ (1/r_1)=1\times10^{-2},\ \delta\ (1/r_2)=1\times10^{-6}\quad (\text{図}5\ (a))\\
&\delta\ (1/r_1)=1\times10^{-2},\ \delta\ (1/r_2)=1\times10^{-4}\quad (\text{図}5\ (b))\\
&\delta\ (1/r_1)=1\times10^{0},\ \delta\ (1/r_2)=1\times10^{-6}\quad (\text{図}6\ (a))\\
&\delta\ (1/r_1)=1\times10^{0},\ \delta\ (1/r_2)=1\times10^{-4}\quad (\text{図}6\ (b))
\end{aligned}
\qquad (26)
$$

また固有値s_1，s_2が両方含まれているのが以下に示す場合（（２７）式）である。

【００４２】

【数２３】

$$
\begin{aligned}
&\delta\ (1/r_1)=1\times10^{-4},\ \delta\ (1/r_2)=1\times10^{-2}\quad (\text{図}4\ (c))\\
&\delta\ (1/r_1)=1\times10^{-4},\ \delta\ (1/r_2)=1\times10^{0}\quad (\text{図}4\ (d))\\
&\delta\ (1/r_1)=1\times10^{-2},\ \delta\ (1/r_2)=1\times10^{-2}\quad (\text{図}5\ (c))\\
&\delta\ (1/r_1)=1\times10^{-2},\ \delta\ (1/r_2)=1\times10^{0}\quad (\text{図}5\ (d))\\
&\delta\ (1/r_1)=1\times10^{0},\ \delta\ (1/r_2)=1\times10^{-2}\quad (\text{図}6\ (c))\\
&\delta\ (1/r_1)=1\times10^{0},\ \delta\ (1/r_2)=1\times10^{0}\quad (\text{図}6\ (d))
\end{aligned}
\qquad (27)
$$

（２７）式に示したいずれかの変数差分量を設定することにより非線形性補正項ｄの値を探索するための反復計算が平均して効率良く行うことができる。

【００４３】より明確に前記変数差分量の適切な値を設定するには、非線形性補正項ｄの初期値d_0が、積行列（$A_V{}^TA_V$）の固有値分布の最大のものより小さく最小のものより大きくなっているものを設定すればよい。本実施例の場合

【００４４】

【数２４】

$$
\begin{aligned}
&\delta\ (1/r_1)=1\times10^{-6},\ \delta\ (1/r_2)=1\times10^{0}\quad (\text{図}3\ (d))\\
&\delta\ (1/r_1)=1\times10^{-4},\ \delta\ (1/r_2)=1\times10^{0}\quad (\text{図}4\ (d))\\
&\delta\ (1/r_1)=1\times10^{-2},\ \delta\ (1/r_2)=1\times10^{-6}\quad (\text{図}5\ (a))\\
&\delta\ (1/r_1)=1\times10^{-2},\ \delta\ (1/r_2)=1\times10^{-4}\quad (\text{図}5\ (b))\\
&\delta\ (1/r_1)=1\times10^{-2},\ \delta\ (1/r_2)=1\times10^{0}\quad (\text{図}6\ (c))
\end{aligned}
\qquad (28)
$$

の時、この要求は満たされる。

【００４５】さらに定量的に前記変数差分量の適切な値を設定するには、複数の変数r_1，r_2に対応する非線形性補正項初期値の中央値ないし平均値と前記積行列（$A_V{}^TA_V$）の固有値分布の中央値ないし平均値とが略一致するものを設定すればよい。略一致とは、対象によっても異なるが、レンズ設計の場合経験的に10^2から10^3程度で一致していればよいことが分かっている。ここで

$$\delta(1/r)=1\times10^{-8}\sim1\times10^{0} \qquad (30)$$

面間隔ｇに関しては

【００６０】

【数２７】

$$\delta(g)=1\times10^{-8}\sim1\times10^{0} \qquad (31)$$

なる範囲内で最適な値に設定することを考える。今、各変数差分量を１０^{1}きざみで考えると、取り得るすべての組合せは、

【００６１】

【数２８】

$$7^{11}\times4^{11}\cong8.3\times10^{15}\ \text{通り}$$

ということになる。このすべてを、１つ当たり１０$^{-6}$秒で調べたとしても、すべてを調べ終るのには約２６３年という膨大な時間がかかる。これは組合せ最適化問題で厳密な解を求めるのが非常に困難な問題（いわゆるＮＰ完全型の問題）の一種である。この種の問題の近似解を非常に効率良く解く手法として、遺伝的アルゴリズム（Genetic Algorithm）が従来より知られている。遺伝的アルゴリズムは１９６０年代にJ. H. Hollandにより考案されたもので、生物進化のエッセンスをそのままコンピュータ上でシミュレートすることにより、最適化問題を効率良く解く手法である。

【００６２】具体的には図１２に示すような手順で実行される。まずステップＳ１では問題をモデル化して遺伝子型の設定を行う。遺伝子型としては例えば数字の列（１０１００１１０）などを使う。次に、異なる遺伝子を持つ個体（この場合は数字列）を多数作り出す（例えば１０１１０００１，０１１０１０１０，１１１０１１００・・・）（ステップＳ２）。そして作り出した個体の適応性の評価を行う（ステップＳ３）。即ち各個体（数列）を所定の評価関数を用いて評価し、次のステップＳ４で評価の低い個体（数列）を淘汰する。

【００６３】続くステップＳ５では、淘汰されなかった個体を増殖させ、淘汰された個体数を補い、次いで交差（ステップＳ６）、突然変異（ステップＳ７）の処理を行い、得られた個体の適応性が不充分ならステップＳ３～Ｓ７を繰り返す。ここで交差は、特定の遺伝子対を選定して、特定部位の入れ換えを行うものであり、突然変異はある確率で遺伝子のある部位を変化させるものである。

【００６４】以上のような処理を最適な変数差分量の設定に適用する場合、遺伝子型をどのように設定するか及び適応性の評価をどのように行うかがポイントとなる。

【００６５】本実施例では、まず遺伝子型としては、任意の１組の差分量設定値をべき数で表した数列を採用した。即ち、例えば数列の左から右へ、１番目から１１番目までを各曲率半径ｒに関する差分量のべき数値、１２番目から２２番目までを各面間隔ｇに関する差分量のべき数値とし、１／ｒの差分量をすべて１×１０$^{-6}$、ｇの差分量をすべて１×１０$^{-3}$とするとき、この状態を表わす遺伝子列を

$$-6-6-6-6-6-6-6-6-6-6-6-3-3-3-3-3-3-3-3-3-3-3 \qquad (32)$$

とおく。このとき、前記固有値分布を調べると、図１１（ａ）に示すようになった。この状態を出発点として、図１１（ａ）のような固有値分布に図１０のような重み付け分布をかけあわせて評価値とし、前記遺伝的アルゴリズムにより、適切な変数差分量を設定するための処理を行う。その結果得られた変数差分量設定値は、曲率半径ｒ、面間隔ｇについてそれぞれ以下のようになった。

【００６６】一方、適応性の評価には、積行列（$A_V{}^TA_V$）の固有値分布の情報を用いる。より具体的には、非線形性補正項の初期値d_0が積行列（$A_V{}^TA_V$）の固有値の内の最大のものより小さく最小のものより大きい値となるものほど、高い評価結果が得られるようにする。

【００６７】より厳密に適応性を評価しようとする場合には、前記初期値d_0の中央値あるいは平均値を前記固有値分布の中央値あるいは平均値とを比較し、それらが略一致する場合、高い評価が得られるようにする。

【００６８】本実施例では、図１０に示すような分布の重み付けを施し、前記固有値がｄ探索範囲外よりも範囲内のほうが評価値が高くなるように、かつ、ｄ探索範囲内でも非線形性補正項初期値d_0に近いほど評価が高くなるようにした。

【００６９】具体的な数値例で説明すると、まず変数差分量を面の曲率半径ｒと面間隔ｇとをそれぞれ共通に

【００７０】

【数２９】

$$\delta(1/r)=1\times10^{-6}$$

$$\delta(g)=1\times10^{-3} \qquad (33)$$

【００７１】

【数３０】

$$\delta(1/r)=1\times10^{-5}\sim1\times10^{-2}$$

$$\delta(g)=1\times10^{-3}\sim1\times10^{-1} \qquad (34)$$

この変数差分量設定値（３４）に対応する固有値分布を調べると図１１（ｂ）に示すようになった。図１１（ａ）と（ｂ）とを比較すれば明らかなように、上述した処理によって、前記固有値分布が非線形性補正項初期値d_0（＝１．０）付近に集まっていることが分かる。

【００７２】上述した処理の前後での、正規化されたメリット関数値、および計算に要した反復回数を比較すると、以下のようになった。

【００７３】

$\delta(1/r_1)=1\times10^{-6}, \delta(1/r_2)=1\times10^{-6}$
$p_1^2=8.6\times10^{-13}, p_2^2=2.2\times10^{-8}$（図３（a））
$\delta(1/r_1)=1\times10^{-6}, \delta(1/r_2)=1\times10^{-4}$
$p_1^2=8.0\times10^{-10}, p_2^2=2.3\times10^{-7}$（図３（b））
$\delta(1/r_1)=1\times10^{-6}, \delta(1/r_2)=1\times10^{-2}$
$p_1^2=9.0\times10^{-10}, p_2^2=2.1\times10^{-8}$（図３（c））
$\delta(1/r_1)=1\times10^{-6}, \delta(1/r_2)=1\times10^{0}$
$p_1^2=5.5\times10^{-9}, p_2^2=6.8\times10^{0}$（図３（d））
$\delta(1/r_1)=1\times10^{-4}, \delta(1/r_2)=1\times10^{-6}$
$p_1^2=8.6\times10^{-13}, p_2^2=2.2\times10^{-4}$（図４（a））
$\delta(1/r_1)=1\times10^{-4}, \delta(1/r_2)=1\times10^{-4}$
$p_1^2=8.6\times10^{-9}, p_2^2=2.2\times10^{-4}$（図４（b））
$\delta(1/r_1)=1\times10^{-4}, \delta(1/r_2)=1\times10^{-2}$
$p_1^2=8.2\times10^{-8}, p_2^2=2.3\times10^{-3}$（図４（c））
$\delta(1/r_1)=1\times10^{-4}, \delta(1/r_2)=1\times10^{0}$
$p_1^2=5.5\times10^{-6}, p_2^2=6.8\times10^{0}$（図４（d））
$\delta(1/r_1)=1\times10^{-2}, \delta(1/r_2)=1\times10^{-6}$
$p_1^2=8.6\times10^{-13}, p_2^2=2.2\times10^{0}$（図５（a））
$\delta(1/r_1)=1\times10^{-2}, \delta(1/r_2)=1\times10^{-4}$
$p_1^2=8.6\times10^{-9}, p_2^2=2.2\times10^{0}$（図５（b））
$\delta(1/r_1)=1\times10^{-2}, \delta(1/r_2)=1\times10^{-2}$
$p_1^2=2.2\times10^{0}, p_2^2=8.7\times10^{-5}$（図５（c））
$\delta(1/r_1)=1\times10^{-2}, \delta(1/r_2)=1\times10^{0}$
$p_1^2=4.3\times10^{-1}, p_2^2=8.5\times10^{0}$（図５（d））
$\delta(1/r_1)=1\times10^{0}, \delta(1/r_2)=1\times10^{-6}$
$p_1^2=5.8\times10^{-13}, p_2^2=5.2\times10^{+8}$（図６（a））
$\delta(1/r_1)=1\times10^{0}, \delta(1/r_2)=1\times10^{-4}$
$p_1^2=5.8\times10^{-9}, p_2^2=5.2\times10^{+3}$（図６（b））
$\delta(1/r_1)=1\times10^{0}, \delta(1/r_2)=1\times10^{-2}$
$p_1^2=5.9\times10^{-5}, p_2^2=5.2\times10^{+8}$（図６（c）
$\delta(1/r_1)=1\times10^{0}, \delta(1/r_2)=1\times10^{0}$
$p_1^2=1.5\times10^{0}, p_2^2=5.2\times10^{+8}$（図６（d））

(39)

これから明らかなようにヤコビ行列A_Vの特異値の自乗値の分布は、前記積行列（$A_V{}^TA_V$）の固有値の分布と全く同じとなる。即ち、ヤコビ行列A_Vの特異値の自乗値$p_1{}^2$，$p_2{}^2$は、積行列（$A_V{}^TA_V$）の固有値と等しい。

【００８３】よって、第１の実施例において積行列（$A_V{}^TA_V$）の固有値s_1，s_2を、ヤコビ行列A_Vの特異値の自乗値$p_1{}^2$，$p_2{}^2$に置き換えたものが本実施例に相当し、本実施例によっても第１の実施例と同様の効果を奏する。

【００８４】また、第２の実施例においても同様の置き換えが可能である。

【００８５】

【発明の効果】以上詳述したように請求項１の設計支援装置又は請求項１５の設計支援方法によれば、複数の構成要素に対応する変数の差分量に対する系の特性の変化量を要素に持つヤコビ行列（A_V）と該ヤコビ行列の転置行列（$A_V{}^T$）との積で構成される積行列（$A_V{}^TA_V$）の固有値分布情報が演算され、該固有値分布情報を用いて前記変数の差分量が設定されるので、降下法による最適値の演算を効率良く行い、最適な設計値を効率良く得ることができる。

【００８６】また、請求項８の設計支援装置又は請求項２２の設計支援方法によれば、複数の構成要素に対応する変数の差分量に対する前記系の特性の変化量を要素に持つヤコビ行列（A_V）の特異値の自乗値分布情報が演算され、該自乗値分布情報を用いて前記変数の差分量が設定されるので、上記同様の効果を奏する。

【図面の簡単な説明】

【図１】本発明の一実施例に係る設計支援装置の構成を示す図である。

【図２】設計の対象とした第１のレンズの系の構成を示す図である。

【図３】ヤコビ行列とその転置行列の積行列の固有値（ヤコビ行列の特異値の自乗値）の分布を示す図である。

【図４】ヤコビ行列とその転置行列の積行列の固有値（ヤコビ行列の特異値の自乗値）の分布を示す図である。

【図５】ヤコビ行列とその転置行列の積行列の固有値（ヤコビ行列の特異値の自乗値）の分布を示す図である。

【図６】ヤコビ行列とその転置行列の積行列の固有値（ヤコビ行列の特異値の自乗値）の分布を示す図である。

【図７】重み付け情報（重み付け関数）の一例を示す図である。

【図８】重み付け情報（重み付け関数）の一例を示す図である。

【図９】設計の対象とした第２のレンズ系の構成を示す図である。

【図１０】重み付け情報（重み付け関数）の一例を示す図である。

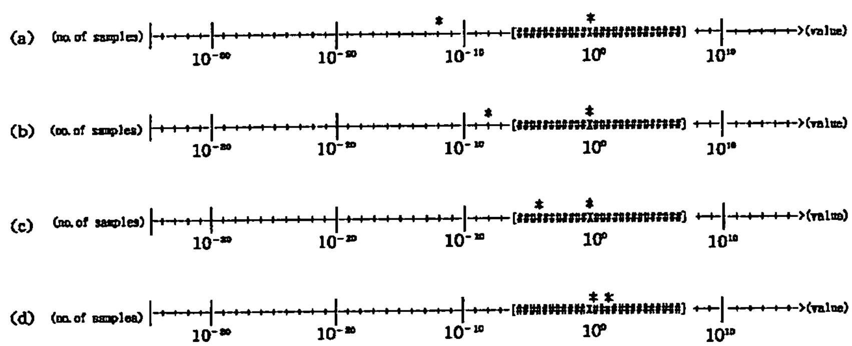
【図１１】ヤコビ行列とその転置行列の積行列の固有値（ヤコビ行列の特異値の自乗値）の分布を示す図である。

【図１２】遺伝子的アルゴリズムの手順を示すフローチャートである。

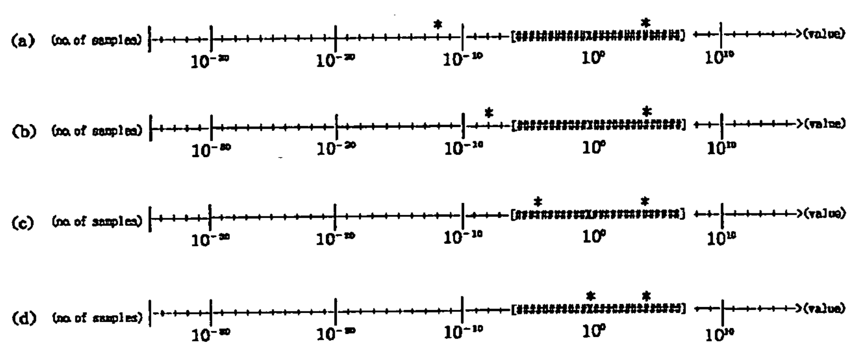
【符号の説明】

１　ＣＰＵ
２　入力装置
３　記憶装置
４　出力装置

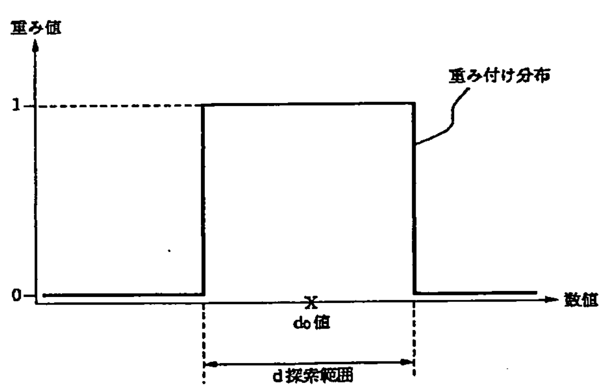
【図5】



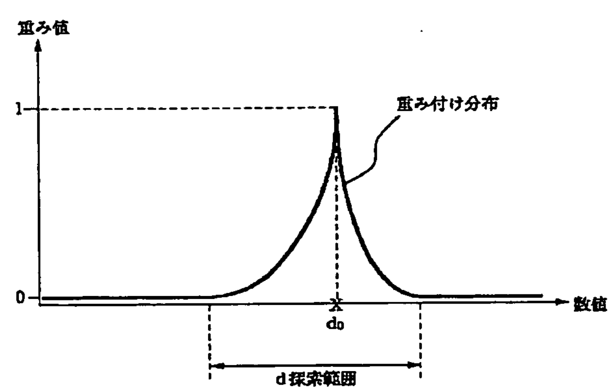
【図6】



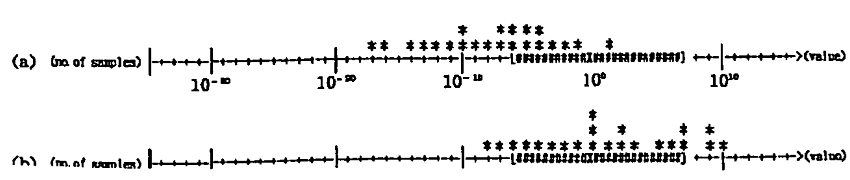
【図7】



【図8】



【図１１】



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(71) Applicant: CANON Inc.

(72) Inventor: Hiroshi MATSUI

(74) Agent: Patent Attorney, Toshihiko WATABE

(54) [Title of the Invention] METHOD AND DEVICE FOR SUPPORTING DESIGN OF LENS OR THE LIKE

(57) [Abstract]

[Object] To efficiently calculate an optimal design value by adequately setting a variable difference amount in the design of a lens or the like by an attenuation least square method.

[Solving Means] A CPU 1 calculates eigen value distribution information on the product matrix (Av^TAv) of the Jacobian matrix Av with the variable amount of the characteristic (an evaluation function Fv(Xv)) of the system for the variable difference amount δxj of the system being a design object as elements thereof and the transposed matrix Av^T and sets the variable difference amount δxj by using the eigen value distribution information. The square value of

the singular value of the Jacobian matrix A may be used in place of the eigen value of the product matrix (Av^TAv).

[Claims]

[Claim 1] A design supporting device to support the design of a lens or the like by a descent method for locally changing and optimizing a plurality of components so that a system of a design object comprising the plurality of components has a desired characteristic comprising:

an eigen value distribution information operating means to operate eigen value distribution information on the product matrix (Av^TAv) constituted of the product of the Jacobian matrix (Av) with the variable amount of the characteristic of the system to the difference amount of the variables corresponding to the plurality of components as the elements thereof and the transposed matrix (Av^T) of the Jacobian matrix; and

a difference amount setting means to set the difference amount of the variables by using the eigen value distribution information.

[Claim 2] The design supporting device according to Claim 1, wherein the difference amount of the variables is set so that the initial value of the non-linear correction term corresponding to the variable for an optimizing objective function is present between the minimum value and the maximum value of the eigen value distribution of the product matrix.

[Claim 3] The design supporting device according to Claim 1,

wherein the difference amount of the variables is set so that the median of the eigen value distribution of the product matrix is substantially matched with the median of the initial value of the non-linear correction term corresponding to the variables for an optimizing objective function.

[Claim 4] The design supporting device according to Claim 1, wherein the difference amount of the variables is set so that the mean of the eigen value distribution of the product matrix is substantially matched with the median of the initial value of the non-linear correction term corresponding to the variables for an optimizing objective function.

[Claim 5] The design supporting device according to Claim 1, wherein the difference amount of the variables is set so that the median of the eigen value distribution of the product matrix is substantially matched with the mean of the initial value of the non-linear correction term corresponding to the variables for an optimizing objective function.

[Claim 6] The design supporting device according to Claim 1, wherein the difference amount of the variables is set so that the mean of the eigen value distribution of the product matrix is substantially matched with the mean of the initial value of the non-linear correction term corresponding to the

variables for an optimizing objective function.

[Claim 7] The design supporting device according to Claim 1, wherein the difference amount of the variables is set by using eigen value distribution information on the product matrix and predetermined weighting information set corresponding to the eigen value distribution.

[Claim 8] A design supporting device to support the design of a lens or the like by a descent method for locally changing and optimizing a plurality of components so that a system of a design object comprising the plurality of components has a desired characteristic comprising:

a square value distribution information operating means to operate square value distribution information on the eigen value of the Jacobian matrix (Av) with the variable amount of the characteristic of the system to the difference amount of the variables corresponding to the plurality of components as the elements thereof; and

a difference amount setting means to set the difference amount of the variables by using the square value distribution information.

[Claim 9] The design supporting device according to Claim 8, wherein the difference amount of the variables is set so that the initial value of the non-linear correction term corresponding to the variables to an optimizing objective function is present between the minimum value and the

maximum value of the square value distribution of the eigen values of the Jacobian matrix.

[Claim 10] The design supporting device according to Claim 8, wherein the difference amount of the variables is set so that the median of the square value distribution of the eigen value of the Jacobian matrix is substantially matched with the median of the initial value of the non-linear correction term corresponding to the variables to an optimizing objective function.

[Claim 11] The design supporting device according to Claim 8, wherein the difference amount of the variables is set so that the mean of the square value distribution of the eigen value of the Jacobian matrix is substantially matched with the median of the initial value of the non-linear correction term corresponding to the variables to an optimizing objective function.

[Claim 12] The design supporting device according to Claim 8, wherein the difference amount of the variables is set so that the median of the square value distribution of the eigen value of the Jacobian matrix is substantially matched with the mean of the initial value of the non-linear correction term corresponding to the variables to an optimizing objective function.

[Claim 13] The design supporting device according to Claim 8, wherein the difference amount of the variables is set so

that the mean of the square value distribution of the eigen value of the Jacobian matrix is substantially matched with the mean of the initial value of the non-linear correction term corresponding to the variables to an optimizing objective function.

[Claim 14] The design supporting device according to Claim 8, wherein the difference amount of the variables is set by using square value distribution information on the eigen value of the Jacobian matrix and predetermined weighting information set corresponding to the square value distribution.

[Claim 15] A design supporting method to support the design of a lens or the like by a descent method for locally changing and optimizing a plurality of components so that a system of a design object comprising the plurality of components has a desired characteristic comprising:

a step of operating eigen value distribution information on the product matrix (Av^TAv) constituted of the product of the Jacobian matrix (Av) with the variable amount of the characteristic of the system to the difference amount of the variables corresponding to the plurality of components as the elements thereof and the transposed matrix (Av^T) of the Jacobian matrix; and

a step of setting the difference amount of the variables by using the eigen value distribution information.

[Claim 16] The design supporting method according to Claim 15, wherein the difference amount of the variables is set so that the initial value of the of the non-linear correction term corresponding to the variables to an optimizing objective function is present between the minimum value and the maximum value of the eigen value distribution of the product matrix.

[Claim 17] The design supporting method according to Claim 15, wherein the difference amount of the variables is set so that the median of the eigen value distribution of the product matrix is substantially matched with the median of the initial value of the non-linear correction term corresponding to the variables to an optimizing objective function.

[Claim 18] The design supporting method according to Claim 15, wherein the difference amount of the variables is set so that the mean of the eigen value distribution of the product matrix is substantially matched with the median of the initial value of the non-linear correction term corresponding to the variables to an optimizing objective function.

[Claim 19] The design supporting method according to Claim 15, wherein the difference amount of the variables is set so that the median of the eigen value distribution of the product matrix is substantially matched with the mean of the

initial value of the non-linear correction term corresponding to the variables to an optimizing objective function.

[Claim 20] The design supporting method according to Claim 15, wherein the difference amount of the variables is set so that the mean of the eigen value distribution of the product matrix is substantially matched with the mean of the initial value of the non-linear correction term corresponding to the variables to an optimizing objective function.

[Claim 21] The design supporting method according to Claim 15, wherein the difference amount of the variables is set by using eigen value distribution information on the product matrix and predetermined weighting information set corresponding to the eigen value distribution.

[Claim 22] A design supporting method to support the design of a lens or the like by a descent method for locally changing and optimizing a plurality of components so that a system of a design object comprising the plurality of components has a desired characteristic comprising:

a step of operating square value distribution information on the eigen value of the Jacobian matrix (Av) with the variable amount of the characteristic of the system to the difference amount of the variables corresponding to the plurality of components as the elements thereof; and

a step of setting the difference amount of the

variables by using the square value distribution information.

[Claim 23] The design supporting method according to Claim 22, wherein the difference amount of the variables is set so that the initial value of the non-linear correction term corresponding to the variables to an optimizing objective function is present between the minimum value and the maximum value of the square value distribution of the eigen values of the Jacobian matrix.

[Claim 24] The design supporting method according to Claim 22, wherein the difference amount of the variables is set so that the median of the square value distribution of the eigen value of the Jacobian matrix is substantially matched with the median of the initial value of the non-linear correction term corresponding to the variables to an optimizing objective function.

[Claim 25] The design supporting method according to Claim 22, wherein the difference amount of the variables is set so that the mean of the square value distribution of the eigen value of the Jacobian matrix is substantially matched with the median of the initial value of the non-linear correction term corresponding to the variables to an optimizing objective function.

[Claim 26] The design supporting method according to Claim 22, wherein the difference amount of the variables is set so that the median of the square value distribution of the

eigen value of the Jacobian matrix is substantially matched with the mean of the initial value of the non-linear correction term corresponding to the variables to an optimizing objective function.

[Claim 27] The design supporting method according to Claim 22, wherein the difference amount of the variables is set so that the mean of the square value distribution of the eigen value of the Jacobian matrix is substantially matched with the mean of the initial value of the non-linear correction term corresponding to the variables to an optimizing objective function.

[Claim 28] The design supporting method according to Claim 22, wherein the difference amount of the variables is set by using square value distribution information on the eigen value of the Jacobian matrix and predetermined weighting information set corresponding to the square value distribution.

Detailed Description of the Invention

[0001]

[Technical Field of the Invention] The present invention relates to a design supporting device and a design supporting method using an attenuation least square method out of optimization methods to locally changing a plurality of components so that an objective system comprising the plurality of components have desired characteristics, and

for example, it relates to a design supporting device and a design supporting method to support a lens design, an optimum pattern design of an LSI, a building design and the like.

[0002]

[Description of the Related Art] Components to constitute a system as a design object are expressed by variable vectors consisting of n pieces of elements as follows.

[0003]

[Formula 1]

$$X_v = [X_1, \ldots, X_n]^T \qquad (1)$$

And the amount to evaluate the characteristics of the object is expressed by an evaluation function vector consisting of m pieces of elements as follows.

[0004]

[Formula 2]

$$F_v(X_v) = [F_1(X_v), \ldots, F_n(X_v)]^T \qquad (2)$$

[0005]

[Formula 3]

$$F_k(X_v) = w_k\{f_k(X_v)-f_{k,tar}\} \qquad (3)$$

Where, suffix v is added to indicate Xv and Fv are vectors (or matrix). Further, fk(Xv), fk and tar are the values of the evaluation function to indicate respective characteristic values, and a target value thereof, and wk is a weighting coefficient. A constraint value may be included

in these evaluation functions in addition to the characteristic value intended for a desired value. In the attenuation least square method, a solution is generally obtained so that the amount of deviation (error) from a target value of each evaluation function value is minimized, and an objective function expressed by the following formula is used for a single evaluation scale.

[0006]

[Formula 4]

$$\phi(X_v) = F_v^T(X_v)F_v(X_v) \qquad (4)$$

The objective function expressed by the formula (4) is referred to as a merit function in the field of the lens design, in particular. By applying the Newton-Paphson method to the formula (4), the necessary information of Xv for a local minimum value is given as follows.

[0007]

[Formula 5]

$$(A_v^T A_v + \sum_{i=1}^{m} f_i H_{vi})\, \Delta X_v = -A_v^T F_{v0} \qquad (5)$$

Where, Av is a Jacobian (Jacobi) matrix of Fv(Xv), and defined by Formula (6).

[0008]

[Formula 6]

$$Av=\begin{bmatrix} \frac{\partial F_1}{\partial x_1} & \frac{\partial F_1}{\partial x_2} & \cdots & \frac{\partial F_1}{\partial x_n} \\ \frac{\partial F_2}{\partial x_1} & \frac{\partial F_2}{\partial x_2} & \cdots & \frac{\partial F_2}{\partial x_n} \\ \vdots & \ddots & \ddots & \vdots \\ \frac{\partial F_m}{\partial x_1} & \frac{\partial F_m}{\partial x_2} & \cdots & \frac{\partial F_m}{\partial x_n} \end{bmatrix} \qquad (6)$$

Hvi is the Hesse matrix of the i-th evaluation function, and defined by Formula (7).

[0009]

[Formula 7]

$$Hvi=\begin{bmatrix} \frac{\partial^2 Fi}{\partial^2 x_1} & \frac{\partial^2 Fi}{\partial x_1 \partial x_2} & \cdots & \frac{\partial^2 Fi}{\partial x_1 \partial x_n} \\ \frac{\partial^2 Fi}{\partial x_2 \partial x_1} & \frac{\partial^2 Fi}{\partial x_2 \partial x_2} & \cdots & \frac{\partial^2 Fi}{\partial x_2 \partial x_n} \\ \vdots & \ddots & \ddots & \vdots \\ \frac{\partial^2 Fi}{\partial x_n \partial x_1} & \frac{\partial^2 Fi}{\partial x_n \partial x_2} & \cdots & \frac{\partial^2 Fi}{\partial^2 x_n} \end{bmatrix} \qquad (7)$$

In Formulae (6) and (7), Fi means an i-th element Fi(Xv) of the evaluation function vector Fv(Xv) (Formula (2)). ΔXv is a solution vector to indicate fluctuation of the variable vector to the next step, and expressed as follows.

Generally, in the descent method, an optimum solution is obtained by solving Formula (10) by using a diagonal matrix Dv (Formula (9)) with a parameter (a non-linear correction term) to correct non-linear components of the secondary or higher differential as elements thereof in place of directly solving Formula (5).

[0010]

[Formula 8]

$$\Delta X_v = [\Delta X_1, \ldots, \Delta X_n]^T \qquad (8)$$

[0011]

[Formula 9]

$$D_v = \begin{bmatrix} d_1 & & & 0 \\ & d_2 & & \\ & & \ddots & \\ 0 & & & d_n \end{bmatrix} \qquad (9)$$

[0012]

[Formula 10]

$$(A_v^T A_v + D_v)\Delta X_v = -A_v^T F_{v0} \qquad (10)$$

In the actual numerical calculation, each element a_{ij} of Av is calculated not by using a strict differential coefficient value (Formula 11) shown by Formula (6), but by using the difference value (Formula 12).

[0013]

[Formula 11]

$$a_{ij} = \partial F_i / \partial x_j \qquad (11)$$

$$a_{ij} = \delta F_i / \delta x_j \qquad (12)$$

[0014]

[Problems to be Solved by the Invention] However, the value of the optimum variable difference amount δxj is diversified according to the characteristic of the object system, raising a problem in that, if an inadequate value is given, errors occur in the numerical computation, many iterative calculations are required, and the optimum solution cannot

be efficiently obtained.

[0015] The present invention is achieved in light of this point, and an object of the present invention is to provide a design supporting device and a design supporting method capable of obtaining the optimum solution in a constantly efficient manner by adequately setting the variable difference amount.

[0016]

[Means for Solving the Problems] In order to achieve the above-described object of the present invention, a design supporting device to support the design of a lens or the like by a descent method for locally changing and optimizing a plurality of components so that a system of a design object comprising the plurality of components has a desired characteristic comprises an eigen value distribution information operating means to operate eigen value distribution information on the product matrix (Av^TAv) constituted of the product of the Jacobian matrix (Av) with the variable amount of the characteristic of a system to the difference amount of the variables corresponding to the plurality of components as the elements thereof and the transposed matrix (Av^T) of the Jacobian matrix, and a difference amount setting means to set the difference amount of the variables by using the eigen value distribution information.

[0017] In order to achieve the same object of the present invention, in a design supporting method to support the design of a lens or the like by a descent method for locally changing and optimizing a plurality of components so that a system of a design object comprising the plurality of components has a desired characteristic, eigen value distribution information is operated on the product matrix (Av^TAv) constituted of the product of the Jacobian matrix (Av) with the variable amount of the characteristic of the system to the difference amount of the variables corresponding to the plurality of components as the elements thereof and the transposed matrix (Av^T) of the Jacobian matrix, and the difference amount of the variables is set by using the eigen value distribution information.

[0018] Further, preferably in the design supporting device or the design supporting method, the difference amount of the variables is set so that the initial value of the non-linear correction term corresponding to the variables to an optimizing objective function is present between the minimum value and the maximum value of the eigen value distribution of the product matrix, the difference amount of the variables is set so that the median of the eigen value distribution of the product matrix is substantially matched with the median of the initial value of the non-linear correction term corresponding to the variables to an

optimizing objective function, the difference amount of the variables is set so that the mean of the eigen value distribution of the product matrix is substantially matched with the median of the initial value of the non-linear correction term corresponding to the variables to an optimizing objective function, the difference amount of the variables is set so that the mean of the eigen value distribution of the product matrix is substantially matched with the median of the initial value of the non-linear correction term corresponding to the variables to an optimizing objective function, the difference amount of the variables is set so that the median of the eigen value distribution of the product matrix is substantially matched with the mean of the initial value of the non-linear correction term corresponding to the variables to an optimizing objective function, the difference amount of the variables is set so that the mean of the eigen value distribution of the product matrix is substantially matched with the mean of the initial value of the non-linear correction term corresponding to the variables to an optimizing objective function, and the difference amount of the variables is set by using eigen value distribution information on the product matrix and predetermined weighting information set corresponding to the eigen value distribution.

[0019] In addition, in the design supporting device or the design supporting method, the "square value distribution of the singular values of the Jacobian matrix (Av)" may be used in place of the "eigen value distribution of the product matrix (Av^TAv)".

[0020]

[Operation] According to the device of Claim 1 or according to the method of Claim 15, eigen value distribution information on the product matrix (Av^TAv) of the Jacobian matrix (Av) with the variable amount of the characteristic of the system to the difference amount of the variables corresponding to a plurality of components as the elements thereof and the transposed matrix (Av^T) of the Jacobian matrix, and the difference amount of the variables is set by using the eigen value distribution information.

[0021] According to the device of Claim 8 or according to the method of Claim 22, square value distribution information on the singular values of the Jacobian matrix (Av) with the variable amount of the characteristic of the system to the difference amount of the variables corresponding to a plurality of components as the elements thereof is operated, and the difference amount of the variables is set by using the square value distribution information.

[0022]

[Embodiments] Embodiments of the present invention will be described with reference to the drawings.

[0023] Fig. 1 shows a configuration of a design supporting device according to an embodiment of the present invention. This device comprises a CPU (a Central Processing Unit) 1 to perform various kinds of operations to optimize a variable corresponding to a component of a system for the design object, an input device 2 to input data and operation commands to the CPU 1 by a user, a storage device 3 to store programs executed by the CPU 1 and data or the like under operations, and an output device 4 to display the result of operations on a display device or to print the result of operations by a printer. These components 1 to 4 are connected to each other by a bus 5.

[0024] Next, the outline of the processing executed by the CPU 1 will be described.

[0025] Firstly, the product matrix (Av^TAv) of the above-described Jacobian matrix Av and a transposed matrix Av^T thereof is subjected to the eigen value break-down as follows.

[0026]

[Formula 12]

$$(A_v^T A_v) = V_v S_v V_v^T \qquad (13)$$

Where, Vv denotes an orthogonal matrix, and Sv denotes an diagonal matrix of n, n-type with n-eigen values of the

product matrix ($Av^T Av$) as elements as shown in Formula (14).

[0027]

[Formula 13]

$$Sv = \begin{bmatrix} S_1 & & 0 \\ & \ddots & \\ 0 & & S_n \end{bmatrix} \qquad (14)$$

The distribution of n- eigen values s1, ... sn which are thus obtained is generally changed as the difference amount δxj of the above-described variable is changed. In this case, the following method is employed in the present embodiment to directly control n-eigen value distribution by the difference amount δxj.

[0028] Firstly, attention is paid to a linear approximation in a vicinity of Xv0 of the above-described evaluation function vector Fv(Xv) as expressed below.

[0029]

[Formula 14]

$$F_v(X_v) = F_v(X_{v0}) + A_v \Delta X_v \qquad (15)$$

Then, the i-th element of the evaluation function vector Fv(Xv) will be expressed as follows (Formula (16)).

[0030]

[Formula 15]

$$\begin{aligned} F_i(X_v) &= F_i(X_{v0}) + \left(\frac{\delta F_i}{\delta x_1}\right)\Delta X_1 + \cdots + \left(\frac{\delta F_i}{\delta x_n}\right)\Delta X_n \\ &= F_i(X_{v0}) + \delta_1 F_i\left(\frac{\Delta X_1}{\delta x_1}\right) + \cdots + \delta_n F_i\left(\frac{\Delta X_n}{\delta x_n}\right) \qquad (16) \end{aligned}$$

In Formula (16), δjFi denotes the variable amount by the i-th variable of the i-th evaluation function. From the relationship of Formula (16), it is proved that completely similar optimum operation can be performed even by using the matrix Av' and the vector ΔXv' such as in Formulae (17) and (18) in place of the Jacobian matrix Av (Formula (6)) and the solution vector ΔXv (Formula (8)).

[0031]

[Formula 16]

$$Av' = \begin{bmatrix} \delta_1 F_1 & \delta_2 F_1 & \cdots & \delta_n F_1 \\ \delta_1 F_2 & \delta_2 F_2 & \cdots & \delta_n F_2 \\ \vdots & \ddots & \ddots & \vdots \\ \delta_1 F_m & \delta_2 F_m & \cdots & \delta_n F_m \end{bmatrix} \qquad (17)$$

$$\Delta Xv' = \left[\left(\frac{\Delta X_1}{\delta x_1} \right), \cdots, \left(\frac{\Delta X_n}{\delta x_n} \right) \right]^T \qquad (18)$$

By this method, the value of each element of the Jacobian matrix can be directly changed by the difference amount δxj of the variable, and n-eigen values of s1 to sn can be freely controlled.

[0032] As described above, it is determined whether or not the set variable difference amount δxj is an adequate value from the relationship between distribution of n-eigen values s1 to sn by the difference amount δxj of the variable which is once given and the initial value of the damping factor ρ, and the optimum difference amount is set by changing the variable difference amount δxj so as to obtain a more

adequate value by using the information, and the optimal design value is efficiently obtained.

[0033] Next, the present invention will be described more specifically by an example of the lens design.

[0034] In the following specific example, the non-linear correction term di is expressed by a common d for simplicity, and the diagonal matrix Dv with the non-linear correction terms as elements thereof is expressed by Formula (19).

[0035]

[Formula 17]

$$Dv = \begin{bmatrix} d & & & 0 \\ & d & & \\ & & \ddots & \\ 0 & & & d \end{bmatrix} \tag{19}$$

Fig. 2 shows a thin-walled lens model as the design object according to the first embodiment of the present invention. In Fig. 2, the lens has a thickness so as to easily show the embodiment. However, the lens thickness and the spacing in the calculation are set to be zero. The radius of curvature r3 is used so that the focal distance of the entire system is correctly 1 to this lens system, and remaining two radii of curvature r1 and r2 are defined as variables. The tertiary spherical difference coefficient and the coma aberration coefficient are employed as two evaluation functions. The initial shape is expressed by the coordinates of (1/r1, 1/r2) as follows.

$1/r1 = -1.8$, and $1/r2 = 0.5$ (20)

The difference amounts $\delta(1/r1)$ and $\delta(1/r2)$ of these two variables $(1/r1)$ and $(1/r2)$ are set in a range specified as follows.

[0036]

[Formula 18]

$$\delta(1/r_1) = 1 \times 10^{-5} \sim 1 \times 10^{0},\ \delta(1/r_2) = 1 \times 10^{-5} \sim 1 \times 10^{0} \quad (21)$$

In addition, the variable difference amount to be set may be selected from four cases for each variable, i.e., sixteen in total at every 10^2 in the range of Formula (21). Generally, in the lens design, the range of the variable difference amount to be roughly set is empirically understood according to the kind of the variables.

[0036] In this condition, the Jacobian matrix Av for two variables and two evaluation functions in each variable difference amount set value is obtained. Two eigen values s1 and s2 of the product matrix (Av^TAv) are calculated as follows (entirely expressed by Formula (22)).

[0038]

[Formula 19]

$\delta(1/r_1) = 1 \times 10^{-6}$, $\delta(1/r_2) = 1 \times 10^{-6}$

$s_1 = 8.6\text{x}10^{-13}$, $s_2 = 2.2\text{x}10^{-8}$ (Fig. 3(a))

$\delta(1/r_1) = 1\text{x}10^{-6}$, $\delta(1/r_2) = 1\text{x}10^{-4}$

$s_1 = 8.0\text{x}10^{-10}$, $s_2 = 2.3\text{x}10^{-7}$ (Fig. 3(b))

$\delta(1/r_1) = 1 \times 10^{-6}$, $\delta(1/r_2) = 1 \times 10^{-2}$

$s_1 = 9.0 \times 10^{-10}$, $s_2 = 2.1 \times 10^{-8}$ (Fig. 3(c))

$\delta(1/r_1) = 1 \times 10^{-6}$, $\delta(1/r_2) = 1 \times 10^{0}$

$s_1 = 5.5 \times 10^{-9}$, $s_2 = 6.8 \times 10^{0}$ (Fig. 3(d))

$\delta(1/r_1) = 1 \times 10^{-4}$, $\delta(1/r_2) = 1 \times 10^{-6}$

$s_1 = 8.6 \times 10^{-13}$, $s_2 = 2.2 \times 10^{-4}$ (Fig. 4(a))

$\delta(1/r_1) = 1 \times 10^{-4}$, $\delta(1/r_2) = 1 \times 10^{-4}$

$s_1 = 8.6 \times 10^{-9}$, $s_2 = 2.2 \times 10^{-4}$ (Fig. 4(b))

$\delta(1/r_1) = 1 \times 10^{-4}$, $\delta(1/r_2) = 1 \times 10^{-2}$

$s_1 = 8.2 \times 10^{-6}$, $s_2 = 2.3 \times 10^{-3}$ (Fig. 4(c))

$\delta(1/r_1) = 1 \times 10^{-4}$, $\delta(1/r_2) = 1 \times 10^{0}$

$s_1 = 5.5 \times 10^{-6}$, $s_2 = 6.8 \times 10^{0}$ (Fig. 4(d))

$\delta(1/r_1) = 1 \times 10^{-2}$, $\delta(1/r_2) = 1 \times 10^{-6}$

$s_1 = 8.6 \times 10^{-13}$, $s_2 = 2.2 \times 10^{0}$ (Fig. 5(a))

$\delta(1/r_1) = 1 \times 10^{-2}$, $\delta(1/r_2) = 1 \times 10^{-4}$

$s_1 = 8.6 \times 10^{-9}$, $s_2 = 2.2 \times 10^{0}$ (Fig. 5(b))

$\delta(1/r_1) = 1 \times 10^{-2}$, $\delta(1/r_2) = 1 \times 10^{-2}$

$s_1 = 2.2 \times 10^{0}$, $s_2 = 8.7 \times 10^{-5}$ (Fig. 5(c))

$\delta(1/r_1) = 1 \times 10^{-2}$, $\delta(1/r_2) = 1 \times 10^{0}$

$s_1 = 4.3 \times 10^{-1}$, $s_2 = 8.5 \times 10^{0}$ (Fig. 5(d))

$\delta(1/r_1) = 1 \times 10^{0}$, $\delta(1/r_2) = 1 \times 10^{-6}$

$s_1 = 5.8 \times 10^{-13}$, $s_2 = 5.2 \times 10^{+3}$ (Fig. 6(a))

$\delta(1/r_1) = 1 \times 10^{0}$, $\delta(1/r_2) = 1 \times 10^{-4}$

$s_1 = 5.8 \times 10^{-9}$, $s_2 = 5.2 \times 10^{+3}$ (Fig. 6(b))

$\delta(1/r_1) = 1 \times 10^{0}$, $\delta(1/r_2) = 1 \times 10^{-2}$

$s_1 = 5.9 \times 10^{-6}$, $s_2 = 5.2 \times 10^{+3}$ (Fig. 6(c))

$\delta(1/r_1) = 1 \times 10^0$, $\delta(1/r_2) = 1 \times 10^0$

$s_1 = 1.5 \times 10^0$, $s_2 = 5.2 \times 10^{+3}$ (Fig. 6(d))

(22)

As described above, the eigen value distribution of each product matrix (Av^TAv) is indicated in Fig. 3(a) to Fig. 6(d). These figures indicate the eigen value distribution operated by the CPU 1 and printed by the output device 4. In each figure, the numerals are exponentially indicated on the horizontal axis, and the position of each eigen value (s1, s2) is indicated by *. Further, the position of the initial value d0 of the non-linear correction term d0 is indicated by X on the horizontal axis, and the search range of the non-linear correction term d0 therearound (hereinafter, referred to as "d search range") is indicated by [## ... ##]. In the present embodiment, d0 is set as follows.

$d0 = 1.0$ (23)

In addition, the ρ search range is set as follows.

[0039]

[Formula 20]

$d0 \times 10^{-6} \sim d0 \times 0.5 \times 10^{8}$ (24)

In the present invention, an adequate value of the difference amount of the variable is set from eigen value distribution information on the product matrix (Av^TAv), and

it is empirically understood in the field of the lens design to set one including the eigen values s1 and s2 in the d search range as many as possible. In this case, as clearly shown in Figs. 3 to 6, one including no eigen values s1 and s2 in the d search range is a case shown below (Formula (25)).

[0040]

[Formula 21]

$\delta(1/r_1) = 1 \times 10^{-6}$, $\delta(1/r_2) = 1 \times 10^{-6}$ (Fig. 3(a))

$\delta(1/r_1) = 1 \times 10^{-6}$, $\delta(1/r_2) = 1 \times 10^{-4}$ (Fig. 3(b))

(25)

Further, one including one eigen value (s1 or s2) is the case shown below (Formula (26)).

[0041]

[Formula 22]

$\delta(1/r_1) = 1 \times 10^{-6}$, $\delta(1/r_2) = 1 \times 10^{-2}$ (Fig. 3(c))

$\delta(1/r_1) = 1 \times 10^{-6}$, $\delta(1/r_2) = 1 \times 10^{0}$ (Fig. 3(d))

$\delta(1/r_1) = 1 \times 10^{-4}$, $\delta(1/r_2) = 1 \times 10^{-6}$ (Fig. 4(a))

$\delta(1/r_1) = 1 \times 10^{-4}$, $\delta(1/r_2) = 1 \times 10^{-4}$ (Fig. 4(b))

$\delta(1/r_1) = 1 \times 10^{-2}$, $\delta(1/r_2) = 1 \times 10^{-6}$ (Fig. 5(a))

$\delta(1/r_1) = 1 \times 10^{-2}$, $\delta(1/r_2) = 1 \times 10^{-4}$ (Fig. 5(b))

$\delta(1/r_1) = 1 \times 10^{0}$, $\delta(1/r_2) = 1 \times 10^{-6}$ (Fig. 6(a))

$\delta(1/r_1) = 1 \times 10^{0}$, $\delta(1/r_2) = 1 \times 10^{-4}$ (Fig. 6(b))

(26)

Further, one including both the eigen values s1 and s2

is the case shown below (Formula (27)).

[0042]

[Formula 23]

$\delta(1/r_1) = 1 \times 10^{-4}$, $\delta(1/r_2) = 1 \times 10^{-2}$ (Fig. 4(c))

$\delta(1/r_1) = 1 \times 10^{-4}$, $\delta(1/r_2) = 1 \times 10^{0}$ (Fig. 4(d))

$\delta(1/r_1) = 1 \times 10^{-2}$, $\delta(1/r_2) = 1 \times 10^{-2}$ (Fig. 5(c))

$\delta(1/r_1) = 1 \times 10^{-2}$, $\delta(1/r_2) = 1 \times 10^{0}$ (Fig. 5(d))

$\delta(1/r_1) = 1 \times 10^{0}$, $\delta(1/r_2) = 1 \times 10^{-2}$ (Fig. 6(c))

$\delta(1/r_1) = 1 \times 10^{0}$, $\delta(1/r_2) = 1 \times 10^{0}$ (Fig. 6(d))

(27)

By setting any one of the variable difference amounts shown in Formula (27), iterative calculation to search the value of the non-linear correction term d can be efficiently performed on the average.

[0043] In order to set an adequate value of the variable difference amount more clearly, one in which the initial value d0 of the non-linear correction term d is smaller than the maximum value and larger than the minimum value of the eigen value distribution of the product matrix (Av^TAv).

[0044]

[Formula 24]

$\delta(1/r_1) = 1 \times 10^{-6}$, $\delta(1/r_2) = 1 \times 10^{0}$ (Fig. 3(d))

$\delta(1/r_1) = 1 \times 10^{-4}$, $\delta(1/r_2) = 1 \times 10^{0}$ (Fig. 4(d))

$\delta(1/r_1) = 1 \times 10^{-2}$, $\delta(1/r_2) = 1 \times 10^{-6}$ (Fig. 5(a))

$\delta(1/r_1) = 1 \times 10^{-2}$, $\delta(1/r_2) = 1 \times 10^{-4}$ (Fig. 5(b))

$\delta(1/r_1) = 1 \times 10^{-2}$, $\delta(1/r_2) = 1 \times 10^{0}$ (Fig. 6(c))

(28)

In the present embodiment, this requirement is satisfied.

[0045] In addition, an adequate value of the variable difference amount is quantitatively set, one may be set, in which the median or the mean of the initial value of the non-linear correction term corresponding to a plurality of variables r1 and r2 is substantially matched with the median or the mean of the eigen value distribution of the product matrix (Av^TAv). Substantial matching is different by the object, and it is empirically understood that matching by 10^2 to 10^3 is sufficient for the case of the lens design. Since the initial value d0 of the non-linear correction term d is commonly given to every above-described variable, the median or the mean of the initial value of the non-linear correction term can be expressed as do. In other words, when the median or the mean of the eigen value distribution of the product matrix (Av^TAv) is expressed by sm, the difference amount $\delta(1/r1)$ and $\delta(1/r2)$ of the variable set at that time if ~~p~~0 d satisfies the relationship shown below.

[0046]

[Formula 25]

$$s_m \times 10^{-3} \sim s_m \times 10^{-2} \le \cancel{pm} \le s_m \times 10^{2} \sim sm \times 10^{3} \quad (29)$$

d or zero

In the present embodiment, there are two variables, and

the median and the mean of the eigen value distribution of the product matrix (Av^TAv) are matched with each other. When checking the mean of the eigen value distribution corresponding to the variable difference amount, it is proved that the relationship of Formula (29) is satisfied if being set like Formula (28).

[0047] To set the variable difference amount more automatically, weighting as shown in Fig. 7 may be performed so that the evaluation value becomes higher as more eigen values s1 and s2 are included in the d search range. In Fig. 7, the value on the horizontal axis indicates each eigen value, and the value on the vertical axis indicates the weight on each eigen value. If the eigen value is included in the d search range, 1 is set, otherwise 0 is set. The variable difference amount may be set so that the evaluation value is much higher thereby.

[0048] Further, if the variable difference amounts $\delta(1/r1)$ and $\delta(1/r2)$ are set based on the relationship between the initial value d0 of the non-linear correction term and the eigen value distribution, continuous weighting may be performed so that the value becomes maximum at the initial value d0 of the non-linear correction term shown in Fig. 8, and the value is gradually decreased as being farther therefrom. In addition, weighting information (the weighting function) shown in Figs. 7 and 8 is stored in the

storage device 3.

[0049] The result of the optimum operation by setting the above-described variable difference amount will be described below.

[0050] Firstly, the number of the eigen values in the d search range, the mean of the merit function obtained by the result of calculation, and the mean of the iteration number required in the calculation will be indicated below.

[0051] The merit function value is normalized by the value at the starting point.

[0052]

Number of eigen value	Mean of merit function	Mean of iteration number
0	0.713	13
1	0.036	10
2	0.034	6.7

As clearly shown from this result, the more the number of the eigen values included in the d search range is, the smaller the obtained merit function value is, and the smaller the iteration number is required. Therefore, the design values of the optimum r1 and r2 can be obtained by setting the variable difference amount so that two eigen values are included in the d search range.

[0053] Next, the result will be shown below for the case in which the initial value d0 of the non-linear correction term

is present between the minimum value and the maximum value of the eigen value distribution and the case in which the initial value d0 of the non-linear correction term is not present therebetween.

[0054]

	Mean of merit function	Mean of iteration number
Present:	0.073	6.6
Not present:	0.143	10.3

As clearly shown from this result, by setting the variable difference amount so that the initial value d0 of the non-linear correction term is present between the minimum value and the maximum value of the eigen value distribution, the obtained merit function value becomes small, and the iteration number also becomes small, and the optimal design can be efficiently performed.

[0055] In addition, the result will be shown below for the case in which the difference between the initial value d0 of the non-linear correction term and the mean of the eigen value distribution is expressed by the exponent difference, and the difference is 10^0, 10^3, 10^4, 10^7 and 10^8, respectively.

[0054]

Exponent difference	Mean of merit function	Mean of iteration number
0	0.066	6.6
3	0.005	9.0
4	0.033	13.0
7	0.469	13.0
8	0.958	13.0

As clearly shown from this result, the merit function value is minimized when the exponent difference is about 3, and the iteration number becomes less as the exponent difference is smaller. Therefore, the optimal design can be efficiently performed by setting the variable difference amount so that the exponent difference is within a range of 2 and 3.

[0057] Fig. 9 shows a configuration of a lens system as a design object according to the second embodiment of the present invention.

[0058] In the present embodiment, twenty two variables consisting of lens components are used, and the beam aberration is mainly used for the evaluation function to indicate the characteristic of the lens. The break-down of these twenty-two variables includes eleven surface radii r of curvature, and eleven kinds of spacing g, and the variable difference amounts are set to an optimum value in

terms of the inverse 1/r of the radius of curvature in a range as follows.

[0059]

[Formula 26]

$$\delta(1/r) = 1 \times 10^{-6} \sim 1 \times 10^{0} \quad (30)$$

The variable difference amounts are set to an optimum value in terms of the spacing g in a range as follows.

[0060]

[Formula 27]

$$\delta(g) = 1 \times 10^{-3} \sim 1 \times 10^{0} \quad (31)$$

When each variable difference amount is considered at the interval of 10^{1}, all possible combinations will be given as follows.

[0061]

[Formula 28]

$$7^{11} \times 4^{11} \approx 8.3 \times 10^{15} \text{ cases}$$

Even if all these combinations are checked in 10^{-6} second per combination, it would take an immense amount of time of about 263 years. This is one of the most difficult problems (a so-called NP-completion type problem) to obtain a strict solution in the combination-optimization problem. A genetic algorithm (Genetic Algorithm) has been extensively known as a method to efficiently solve the approximate solution of this kind of problem. The genetic algorithm was devised by J. H. Holland in 1960s, and this is a method for

efficiently solving an optimization problem by simulating the essence of the biological evolution as it is on the computer.

[0062] More specifically, this method is executed by the procedure as shown in Fig. 12. Firstly, in Step S1, the problem is modeled, and the gene type is set. For example, a numerical string (10100110) is used for the gene type. Next, a large number of individuals of different genes (numerical strings in this case) are formed (for example, 10110001, 01101010, 11101100 ...) (Step S2). And, the adaptability of the formed individuals is evaluated (Step S3). In other words, each individual (series) is evaluated by using the predetermined evaluation function, and the individuals (series) of low evaluation will be selected in Step S4.

[0063] In Step S5, the not-selected individuals are multiplied to compensate the number of selected individuals, and the crossing-over (Step S6) and the mutation (Step S7) are performed. If the adaptability of the obtained individuals is insufficient, Steps S3 to S7 will be repeated. Here, the crossing-over is performed by switching specified parts by selecting specified gene pairs, and the mutation is performed by changing some parts of the gene at some probability.

[0064] When the above-described processing is applied to

the setting of the optimum variable difference amount, a point is how the gene type is set and how the adaptability is evaluated.

[0065] In the present embodiment, firstly, the series in which an arbitrary pair of difference amount set values are expressed by the exponent are employed. In other words, the first to eleventh number of the series from the left to the right are set as the exponent value of the difference amount on each radius r of curvature, the twelfth to twenty-second number of the series are set to be the exponent value of the difference amount on each spacing g, all the difference amounts of 1/r are set to be 1×10^{-6}, and all the difference amounts of g are set to be 1×10^{-3}, the gene row to indicate this state is expressed as follows.

-6-6-6-6-6-6-6-6-6-6-6-3-3-3-3-3-3-3-3-3-3-3 (32)

[0066] On the other hand, information on the eigen value distribution of the product matrix (Av^TAv) is used for the evaluation of the adaptability. More specifically, the result of higher evaluation will be obtained when the initial value d0 of the non-linear correction term d0 is smaller than the maximum of the eigen values of the product matrix (Av^TAv), and larger than the minimum thereof.

[0067] When the adaptability is evaluated more strictly, the median or the mean of the initial value d0 is compared with the median or the mean of the eigen value distribution,

and higher evaluation will be obtained when the initial value is substantially matched with the median or the mean of the eigen value distribution.

[0068] In the present embodiment, weighting of the distribution as shown in Fig. 10 is performed, and the evaluation value becomes higher when the eigen value is not outside the d search range but within the range, and higher evaluation is obtained when the eigen value is close to the initial value d0 of the non-linear correction term though it is within the d search range.

[0069] Description will be given by a specifically numerical example. Firstly, in the variable difference amount, the radius r of curvature and the spacing g of the plane are set to be common as follows.

[0070]

[Formula 29]

$$\delta(1/r) = 1 \times 10^{-6}$$

$$\delta(g) = 1 \times 10^{-3} \qquad (33)$$

In this condition, the eigen value distribution is examined as shown in Fig. 11(a). This state forms a starting point, and the weighting distribution in Fig. 10 is multiplied by the eigen value distribution in Fig. 11(a) to obtain the evaluation value, and processing is performed to set an adequate variable difference amount by the genetic algorithm. The variable difference amount set value

obtained as the result is as shown below for the radius r of curvature and the spacing g, respectively.

[0071]

[Formula 30]

$$\delta(1/r) = 1 \times 10^{-5} \sim 1 \times 10^{-2}$$

$$\delta(g) = 1 \times 10^{-3} \sim 1 \times 10^{-1} \qquad (34)$$

The eigen value distribution corresponding to the variable difference amount set value (34) is shown in Fig. 11(b). As clearly shown from the comparison between Fig. 11(a) and Fig. 11(b), it is shown that the eigen value distribution is gathered around the initial value d0 of the non-linear correction term d0 (= 1.0) by the above-described processing.

[0072] Comparison of the normalized merit function value and the iteration number required for the calculation before and after the above-described processing is as follows.

[0073]

	Merit function value	Iteration number of calculation
Before processing	5.0×10^{-3}	3
After processing	1.3×10^{-3}	3

As clearly shown from this result, according to the present embodiment, the convergence efficiency of the descent method can be enhanced.

[0074] Next, the outline of the processing executed by the CPU 1 in the third embodiment of the present invention will

be described.

[0075] Firstly, the Jacobian matrix Av is subjected to the eigen value break-down.

[0076]

[Formula 31]

$$A_v = U_v P_v V_v^T \qquad (35)$$

Where, UvVv denote orthonormal matrixes of m, m type and n, n type, respectively, and when m > n, Pv is expressed as follows.

[0077]

[Formula 32]

$$Pv = \begin{bmatrix} p_1 & & 0 \\ 0 & \ddots & p_n \\ & 0_v & \end{bmatrix} \qquad (36)$$

When m ≤ n, Pv is expressed as follows.

[0078]

[Formula 33]

$$Pv = \begin{bmatrix} p_1 & 0 & \\ \ddots & & 0_v \\ 0 & p_m & \end{bmatrix} \qquad (37)$$

Pv is a singular value matrix with n- or m- singular values of the Jacobian matrix Av as the elements thereof. The product $Pv^T Pv$ of the singular value matrix is expressed as follows.

[0079]

[Formula 34]

$$Pv^{T}Pv=\begin{bmatrix} p_1^2 & & 0 \\ & \ddots & \\ 0 & & pn^2 \end{bmatrix} \qquad (38)$$

The distribution of the square values $p1^2$, ... pn^2 of the thus-obtained n- singular values is changed by the difference amount δxj of the above-described variables. In this condition, in order to directly control the distribution of the square values $p1^2$, ... pn^2 of the thus-obtained n- singular values by the difference amount δxj, a method (Formulae (15) to (18)) similar to that of the first embodiment is employed also in the present embodiment. Therefore, the square values $p1^2$, ... pn^2 of the thus-obtained n- singular values can be freely controlled by the difference amount δxj.

[0080] As described above, it is determined whether or not the set variable difference amount is adequate from the relationship of the square value distribution of the distribution of n- singular values of the once-given variables by the difference amount δxj and the initial value of the non-linear correction term d, and optimum difference amount is set by successively changing the variable difference amount δxj so as to obtain a further adequate value by using the information so that the optimal design value is efficiently obtained.

[0081] The above-described method is applied to the same lens system identical to that of the first embodiment, and the square values $p1^2$ and $p2^2$ of the singular values of the Jacobian matrix Av corresponding to Formula (22) are calculated as follows (the entire values are expressed by Formula (39)).

[0082]

[Formula 35]

$\delta(1/r_1) = 1 \times 10^{-6}$, $\delta(1/r_2) = 1 \times 10^{-6}$

$p_1^2 = 8.6\times10^{-13}$, $p_2^2 = 2.2\times10^{-8}$ (Fig. 3(a))

$\delta(1/r_1) = 1\times10^{-6}$, $\delta(1/r_2) = 1\times10^{-4}$

$p_1^2 = 8.0\times10^{-10}$, $p_2^2 = 2.3\times10^{-7}$ (Fig. 3(b))

$\delta(1/r_1) = 1 \times 10^{-6}$, $\delta(1/r_2) = 1 \times 10^{-2}$

$p_1^2 = 9.0 \times 10^{-10}$, $p_2^2 = 2.1 \times 10^{-8}$ (Fig. 3(c))

$\delta(1/r_1) = 1 \times 10^{-6}$, $\delta(1/r_2) = 1 \times 10^{0}$

$p_1^2 = 5.5 \times 10^{-9}$, $p_2^2 = 6.8 \times 10^{0}$ (Fig. 3(d))

$\delta(1/r_1) = 1 \times 10^{-4}$, $\delta(1/r_2) = 1 \times 10^{-6}$

$p_1^2 = 8.6 \times 10^{-13}$, $p_2^2 = 2.2 \times 10^{-4}$ (Fig. 4(a))

$\delta(1/r_1) = 1 \times 10^{-4}$, $\delta(1/r_2) = 1 \times 10^{-4}$

$p_1^2 = 8.6 \times 10^{-9}$, $p_2^2 = 2.2 \times 10^{-4}$ (Fig. 4(b))

$\delta(1/r_1) = 1 \times 10^{-4}$, $\delta(1/r_2) = 1 \times 10^{-2}$

$p_1^2 = 8.2 \times 10^{-6}$, $p_2^2 = 2.3 \times 10^{-3}$ (Fig. 4(c))

$\delta(1/r_1) = 1 \times 10^{-4}$, $\delta(1/r_2) = 1 \times 10^{0}$

$p_1^2 = 5.5 \times 10^{-6}$, $p_2^2 = 6.8 \times 10^{0}$ (Fig. 4(d))

$\delta(1/r_1) = 1 \times 10^{-2}$, $\delta(1/r_2) = 1 \times 10^{-6}$

$$p_1^2 = 8.6 \times 10^{-13},\ p_2^2 = 2.2 \times 10^{0}\ \text{(Fig. 5(a))}$$

$$\delta(1/r_1) = 1 \times 10^{-2},\ \delta(1/r_2) = 1 \times 10^{-4}$$

$$p_1^2 = 8.6 \times 10^{-9},\ p_2^2 = 2.2 \times 10^{0}\ \text{(Fig. 5(b))}$$

$$\delta(1/r_1) = 1 \times 10^{-2},\ \delta(1/r_2) = 1 \times 10^{-2}$$

$$p_1^2 = 2.2 \times 10^{0},\ p_2^2 = 8.7 \times 10^{-5}\ \text{(Fig. 5(c))}$$

$$\delta(1/r_1) = 1 \times 10^{-2},\ \delta(1/r_2) = 1 \times 10^{0}$$

$$p_1^2 = 4.3 \times 10^{-1},\ p_2^2 = 8.5 \times 10^{0}\ \text{(Fig. 5(d))}$$

$$\delta(1/r_1) = 1 \times 10^{0},\ \delta(1/r_2) = 1 \times 10^{-6}$$

$$p_1^2 = 5.8 \times 10^{-13},\ p_2^2 = 5.2 \times 10^{+3}\ \text{(Fig. 6(a))}$$

$$\delta(1/r_1) = 1 \times 10^{0},\ \delta(1/r_2) = 1 \times 10^{-4}$$

$$p_1^2 = 5.8 \times 10^{-9},\ p_2^2 = 5.2 \times 10^{+3}\ \text{(Fig. 6(b))}$$

$$\delta(1/r_1) = 1 \times 10^{0},\ \delta(1/r_2) = 1 \times 10^{-2}$$

$$p_1^2 = 5.9 \times 10^{-6},\ p_2^2 = 5.2 \times 10^{+3}\ \text{(Fig. 6(c))}$$

$$\delta(1/r_1) = 1 \times 10^{0},\ \delta(1/r_2) = 1 \times 10^{0}$$

$$p_1^2 = 1.5 \times 10^{0},\ p_2^2 = 5.2 \times 10^{+3}\ \text{(Fig. 6(d))} \tag{39}$$

As clearly shown above, the distribution of the square values of the singular values of the Jacobian matrix Av is totally same as the distribution of the eigen values of the product matrix (Av^TAv). In other words, the square values $p1^2$ and $p2^2$ of the singular values of the Jacobian matrix Av are equal to the eigen values of the product matrix (Av^TAv).

[0083] Therefore, in the first embodiment, replacement of the singular values of the eigen values s1 and s2 of the product matrix (Av^TAv) by the square values $p1^2$ and $p2^2$

corresponds to the present embodiment, and similar effect to the first embodiment can also be demonstrated by the present embodiment.

[0084] Further, similar replacement can also be performed even in the second embodiment.

[0085]

[Advantages] As described above in detail, according to the design supporting device of Claim 1, or according to the design supporting method of Claim 15, eigen value distribution information on the product matrix (Av^TAv) constituted of the product of the Jacobian matrix (Av) with the variable amount of the characteristic of the system to the difference amount of the variables corresponding to a plurality of components as the elements thereof and the transposed matrix (Av^T) of the Jacobian matrix is operated, and the difference amount of the variables is set by using the eigen value distribution information. Therefore, the optimum value by the descent method is efficiently operated, and the optimal design value can be efficiently obtained.

[0086] Further, according to the design supporting device of Claim 8 or according to the design supporting method of Claim 22, square value distribution information on the singular values of the Jacobian matrix (Av) with the variable amount of the characteristic of the system to the difference amount of the variables corresponding to a

plurality of components as the elements thereof, and the difference amount of the variables is set by using the square value distribution information, and similar effect can be demonstrated thereby.

[Brief Description of the Drawings]

[Fig. 1] Fig. 1 shows a configuration of a design supporting device according to an embodiment of the present invention.

[Fig. 2] Fig. 2 shows a configuration of a first lens system as a design object.

[Fig. 3] Fig. 3 shows distribution of the eigen value (a square value of a singular value of a Jacobian matrix) of a product matrix of the Jacobian matrix and a transposed matrix thereof.

[Fig. 4] Fig. 4 shows distribution of the eigen value (a square value of a singular value of a Jacobian matrix) of a product matrix of the Jacobian matrix and a transposed matrix thereof.

[Fig. 5] Fig. 5 shows distribution of the eigen value (a square value of a singular value of a Jacobian matrix) of a product matrix of the Jacobian matrix and a transposed matrix thereof.

[Fig. 6] Fig. 6 shows distribution of the eigen value (a square value of a singular value of a Jacobian matrix) a product matrix of the Jacobian matrix and a transposed

matrix thereof.

[Fig. 7] Fig. 7 shows an example of weighting information (a weighting function).

[Fig. 8] Fig. 8 shows an example of weighting information (a weighting function).

[Fig. 9] Fig. 9 shows a configuration of a second lens system as a design object.

[Fig. 10] Fig. 10 shows an example of weighting information (a weighting function).

[Fig. 11] Fig. 11 shows distribution of the eigen value (a square value of a singular value of a Jacobian matrix) a product matrix of the Jacobian matrix and a transposed matrix thereof.

[Fig. 12] Fig. 12 shows a flowchart to indicate the procedure of a genetic algorithm.

[Reference Numerals]

1 CPU

2 input device

3 storage device

4 output device

FIG. 1

2 INPUT DEVICE

3 STORAGE DEVICE

4 OUTPUT DEVICE

FIG. 7

1 WEIGHTING VALUE

2 WEIGHTING DISTRIBUTION

3 NUMERICAL VALUE

4 d0 VALUE

5 d SEARCH RANGE

FIG. 8

1 WEIGHTING VALUE

2 WEIGHTING DISTRIBUTION

3 NUMERICAL VALUE

4 d SEARCH RANGE

FIG. 10

1 WEIGHTING VALUE

2 WEIGHTING DISTRIBUTION

3 NUMERICAL VALUE

4 d0 VALUE

5 d SEARCH RANGE

FIG. 12

S1 SET GENE TYPE

S2 SET GROUP

S3 EVALUATE ADAPTABILITY

S4 SELECTION

S5 MULTIPLICATION

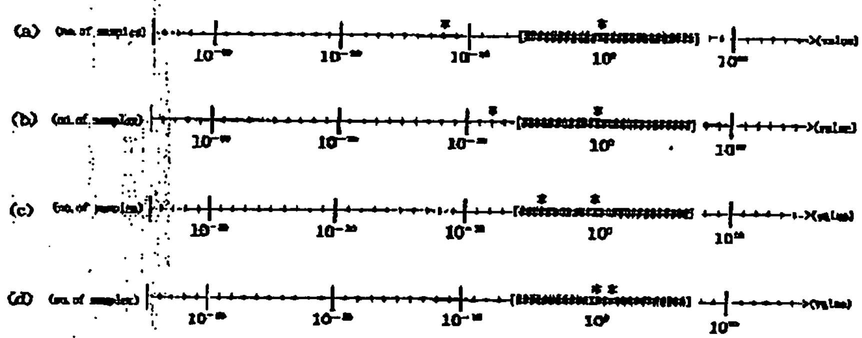
S6 CROSSING-OVER

S7 MUTATION

S8 IS ADAPTABILITY SUFFICIENT?

PU-2

【図５】



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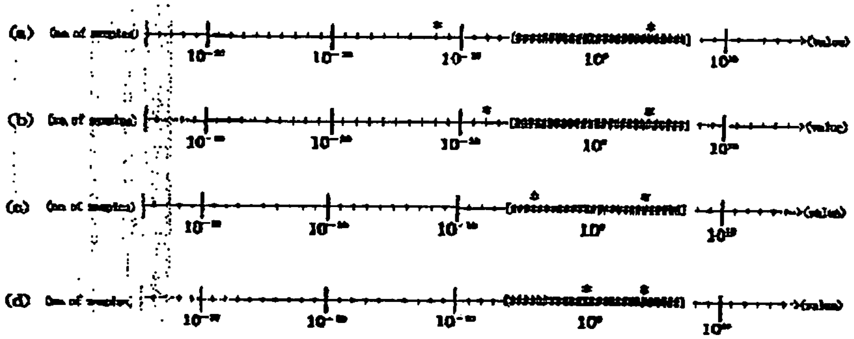

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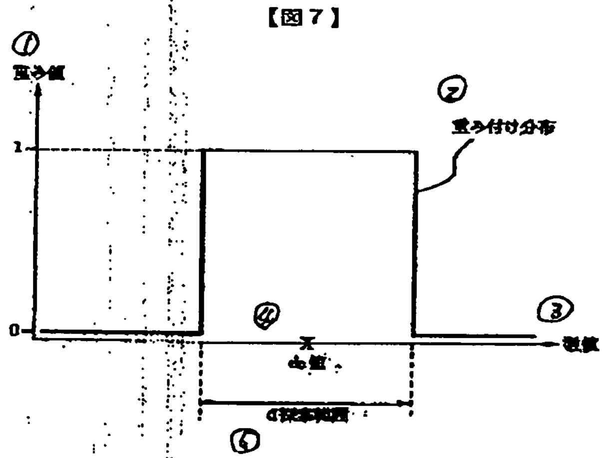

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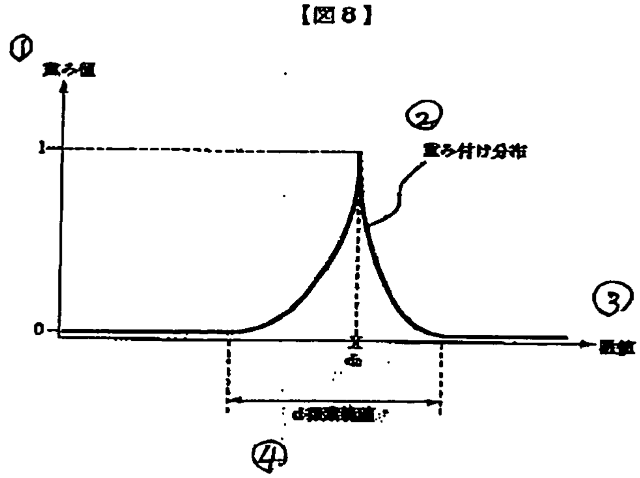

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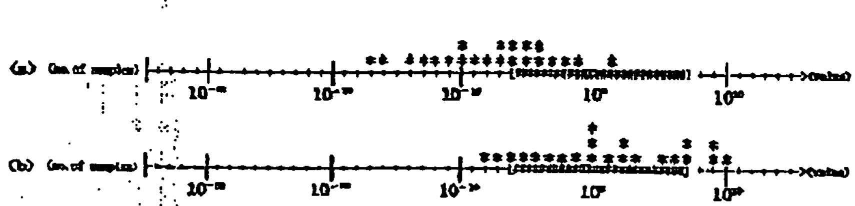
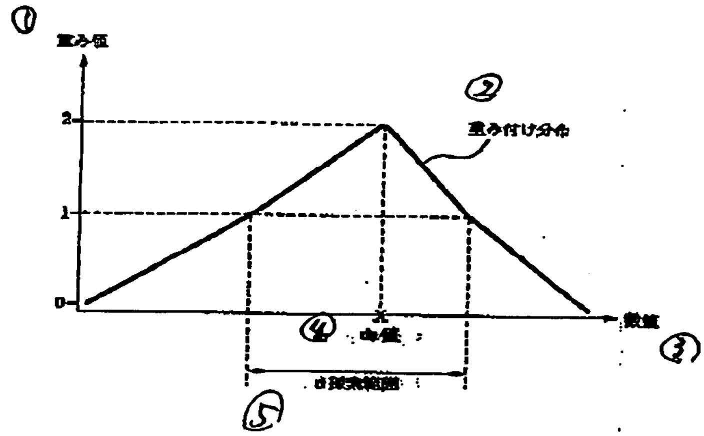


PU-2

【図１０】



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